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THE CHEMICAL CHARACTERIZATION OF ENVIRONMENTAL TOBACCO SMOKE

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ABSTRACT

A detailed characterization of environmental tobacco smoke is needed in order to understand at least four areas which are important to the proper evaluation of the impact of smoking on the nonsmoker in indoor environments: 1. identification of the chemical compounds to which the nonsmoker is exposed, 2. determination of changes in the chemical composition and in the gas-particulate phase distribution of environmental tobacco smoke with time in the indoor environment, 3. identification of substances which may be used to estimate the exposure of the nonsmoker to environmental tobacco smoke in the indoor environment, and 4. risk assessment of disease and irritant exacerbations associated with exposure of the nonsmoker to environmental tobacco smoke. The first three areas are reviewed in this paper.

THE CHEMICAL COMPOSITION OF FRESH ENVIRONMENTAL TOBACCO SMOKE.

Environmental tobacco smoke consists of sidestream smoke generated by a burning cigarette and mainstream smoke exhaled by the smoker. The major contribution to environmental tobacco smoke is from the sidestream smoke from a cigarette. Sidestream and mainstream smoke produced during the smoking of a cigarette are chemically qualitatively similar. However, significant quantitative differences exist between the two sources. In addition, as the generated environmental tobacco smoke emissions are introduced into an indoor environment substantial changes in the gas-particulate phase distribution of the chemical species present occurs.

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Chemical Composition of Sidestream Tobacco Smoke.

The chemical characterization of environmental tobacco smoke has mainly been limited to the comparison of the concentrations of organic (1-7) and inorganic (8,9) constituents in particles of tobacco smoke condensate and total sidestream tobacco smoke, the determination of the main inorganic gases present in environmental tobacco smoke such as CO_2, CO, NH_3, HCN, NO and HNO_2 (1-3,10-12), and the determination of the principal organic compounds present in environmental tobacco smoke in chamber studies (13-19) and in indoor environments where environmental tobacco smoke is present (15,20-27).

The chemical composition of environmental tobacco smoke has been extensively discussed in reviews by the Surgeon General (1) and the National Research council (2). More recent data have been discussed in recent reviews (3,28-30) and in a recent IARC Monograph (31,32). Included in the IARC Monograph and other publications is a review of the combustion conditions associated with the formation of both mainstream and sidestream tobacco smoke (3,33). The major differences between mainstream and sidestream tobacco smoke arises from the lower combustion temperatures associated with the formation of sidestream tobacco smoke (3,33), leading to an increase in the amounts of distillation products and a decrease in the amounts of combustion products present. As a result, sidestream smoke is more alkaline than mainstream smoke (34). This alkalinity results from the increased amounts of N-containing bases present as distillation products in the sidestream smoke aerosol. However, the combustion zone of mainstream smoke is more oxygen deficient than the combustion zone of sidestream smoke and, as a result, the CO_2/CO ratios are higher for sidestream smoke than for mainstream smoke.

The expected composition of freshly generated sidestream tobacco smoke is given in Table I The amounts of most constituents in sidestream tobacco smoke are little effected by brand, tobacco moisture content, or mainstream combustion parameters for combustion of comparable amounts of tobacco (3). As a result, sidestream tobacco smoke emissions, and since sidestream tobacco smoke is responsible for most of the environmental tobacco smoke in indoor environments, environmental tobacco smoke composition in an indoor environment should be predictable from a knowledge of the number of cigarettes smoked as a function of time. This prediction will be altered by changes in the phase distribution and chemical composition of the environmental tobacco smoke as it ages in an indoor environment.

Gas-particulate Phase Distribution of Some Compounds in Environmental Tobacco Smoke.

Little is known about the distribution of organic compounds between the gas and particulate phases of environmental tobacco smoke (2,3,6,13-15,35). Recent studies have shown that most of the volatile nitrogen containing compounds such as nicotine, myosmine and pyridine are predominantly present in the gas phase of environmental tobacco smoke (14-16,18,20,35,36). Acrolein, formaldehyde and acetaldehyde are major toxic constituents of the gas phase of environmental tobacco smoke (1,2). The distribution of many mutagenic and/or toxic compounds, such as the N-nitrosamines, between the gas and particulate phases of environmental tobacco smoke is presently not known (2). For most of the semi-volatile organic compounds the phase of the compound is not well known. The phase distribution of nicotine has been extensively studied. While nicotine is undoubtedly present primarily in the particulate phase in sidestream tobacco smoke generated in small combustion devices (3), it is present as the gas phase species in sidestream tobacco smoke in a chamber (37,38). The equilibration from the particle to the gas phase is very rapid (14,16,39,40). The more alkaline pH of sidestream tobacco smoke (34) may be, in part, responsible for

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Table I. Gas and Particulate Phase Compounds Potentially Useful as Tracers of Environmental Tobacco. (Data are From References 14,15,19,21,41,50,96)

Chemical Class	Class wt% of Particle	Examples of Identified Compounds	µMol Compound/Mol CO Gas Phase	µMol Compound/Mol CO Particles	% Compound in Gas Phase
Particles				4.22±0.82g/mol CO	
Mutagenicity				6.47±1.15revertants/µmolCO	
Alkanes/ Alkenes	3.6±0.5	Phytadiene	-----[a]	138± 13	-----
		n-Hentriacontane	-----	93± 29	-----
		1,3-Butadiene	3100±850	-----	100
		Isoprene	19200±5600	-----	100
		Solanesol	-----	219±43	0
Bases	10.9±1.2	Nicotine	12500±3600	393±150	98.3±1.4
		Myosmine	375± 38	14.7±1.7	96.1±0.9
		Nicotyrine	16± 6	10.6±3.3	60 ±20
		Cotinine	18.2±9.4	17.7±7.0	54.6±12.8
		Pyridine	1180± 72	< 5	100
		3-Ethenylpyridine	1370±460	< 5	100
		2-Ethenylpyridine	207± 36	< 5	100
Sterols	0.5±0.1	Campesterol	-----	6.4±2.4	0
		Stigmasterol	-----	12.1±6.5	0
		β-Sitosterol	-----	9.1±7.5	0
		Cholesterol	-----	5.9±1.3	0
Sterenes[b]	0.4±0.3	24-MeC-3,5-dien	-----	8.8±8.5	0
		24-EtC-3,5,22-trien	-----	6.8±3.4	0
PAH	<0.1	Pyrene	-----	0.02±0.01	-----
		Phenanthrene	-----	0.11±0.02	-----
Inorganic	-----	NO	36700±3200	0	100
		NO_2	2520± 430	0	100
		HNO_3	96± 127	92± 55	44 ±24
		HNO_2	4650±1300	54± 40	98.7± 1.0
		SO_2 + Sulfate	71± 52	71± 40	49 ±23
		NH_3	51900±5400	155± 34	99.6± 0.2
		Potassium	0	840±150	0
		Calcium	0	340±100	0

[a] ----- = not determined.
[b] MeC and EtC = Methylcholesta and Ethylcholesta.

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the rapid displacement of the non-protonated nicotine from the particles (3). In addition to nicotine, nicotyrine, myosmine, pyridine and alkyl pyridine compounds are also present only or predominantly in the gas phase (14,15,20, 39). The identification of the gas-particle phase distribution of organic compounds of toxicological interest is an area of needed research.

There is an apparent difference in total mass in sidestream emissions from a cigarette in studies conducted using a small combustion and collection device as compared to studies conducted using an environmental chamber (29). The chamber studies give emission values which range from 6 to 11 mg particles/cigarette while the other studies give values with 11 mg/cigarette as the lower end of the measurements. The differences cannot be accounted for based on selective deposition loss of particles in the chamber experiments as the data are generally obtained in chambers immediately after combustion of the cigarette (13,14,17,19). The difference appears to be real. Many of the organic constituents of sidestream tobacco smoke are volatile and losses of material from the particles as the smoke is diluted would be expected (41). It is assumed in the data interpretation given in this review that this is the case. The amount of particulate matter in environmental tobacco smoke resulting from the combustion of a cigarette is assumed to be about 10 mg.

If the differences in particulate matter observed in the two types of chemical characterization experiments (chamber vs combustion apparatus) are due to volatilization of organic compounds as the smoke is diluted into a room, then available data (29) suggest that about 1/2 of the generated sidestream particle mass is rapidly lost to the gas phase during dilution and aging in an indoor environment. Gas phase hydrocarbon measurements (14) and the results of radiotracer labeled experiments (42) are consistent with this hypothesis. The existence of large amounts of gas phase hydrocarbons which can be readily condensed back to particulate phase material has also been suggested by chamber experiments involving UV radiation of sidestream environmental tobacco smoke (14). The concentration of particles present in the irradiated sidestream mixture doubles in less than one hour as a result of chemistry induced by the UV radiation. This includes the movement of most of the gas phase nicotine back to the particulate state (13,14). Comparable chemistry apparently occurs in environments with unvented combustion heaters. The gas phase compounds responsible for this observed chemistry are not now known. The identification of gas phase compounds in environmental tobacco smoke may help determine which species are responsible for sensory irritation in sensitive individuals (43-46).

CHANGES DURING THE AGING OF ENVIRONMENTAL TOBACCO SMOKE CONSTITUENTS IN AN INDOOR ENVIRONMENT.

Environmental tobacco smoke is a complex mixture of gas and particulate phase compounds. During aging of environmental tobacco smoke in an indoor environment, changes in the chemical composition will occur. These changes will include coagulation of particles to alter the particle size distribution (13,47,48) changes in the gas/particle distribution of semi-volatile compounds (14), and possible chemical changes due to reactions (13,14,22,39,40,49). In addition, the chemical composition of environmental tobacco smoke may be altered during aging in an indoor environment because of differences in the removal rate of various constituents as the environmental tobacco smoke is aged, is recirculated in the indoor environment and is mixed with outside air (22,23,35,50).

Many gas phase components of environmental tobacco smoke have been shown to be rapidly removed in indoor environments. Several studies have shown that the removal rate for gas phase nicotine and other basic nitrogen compounds is much faster than the removal rates for particles or non-reactive gases such as CO

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(15,18,19,22,23,28,35,39,40,50). The relative removal rates may depend on local environmental factors such as wall coverings, furnishings, presence or absence of people, air flow, etc. Thus, environmental tobacco smoke will be a constantly changing mixture due to loss of material as a result of adsorption or decomposition and due to changes in gas/particulate phase equilibria for volatile species.

Several studies in controlled indoor environments have shown that nicotine is removed much faster than are CO, RSP, NO, gas phase hydrocarbons or specific particulate phase compounds (18,22,23,50,51). The importance of these laboratory observations with respect to environmental tobacco smoke in typical indoor environments is best illustrated by comparing the concentrations of nicotine to fine particulate matter in both controlled and indoor atmospheres. The ratio of RSP to total nicotine has been reported by several investigators. Experiments conducted in chambers with inert walls or in experiments with minimal residence time of the generated sidestream smoke (14,17-19,50,52) give a ratio of about 2-4 g RSP/g nicotine in diluted side stream tobacco smoke. Values determined in sidestream smoke emissions vary from 2 to 6 g RSP/g nicotine (3,4,7,11) with the higher values probably resulting from partial loss of some nicotine to the gas phase during sample collection on a filter (37,38,52). The studies of environmental tobacco smoke conducted in non-Teflon chambers give higher ratios of RSP to nicotine, probably because of the more rapid removal of gas phase nicotine by chamber components (15,18,22,23,50,52). Results from decay studies in chamber or controlled environment experiments are shown in Figure 1. The ratio of nicotine/RSP increases slightly with time in experiments conducted in a Teflon chamber (13,14) because gas phase nicotine is stable in this environment, but the concentration of particles decreases by evaporation and by loss of particles to the chamber walls. In all the other study environments, the rate of decay of gas phase nicotine is greater than the rate of loss of particles.

Steady-state experiments in ventilated chambers with individuals present or in well controlled experimental indoor environments give values of around 10 to 15 g RSP/g nicotine (19,22,23,53-56). This ratio is larger than that which would be seen if people (and the accompanying absorptive surfaces) were not present. For example, in studies in the chamber at the U.S. Environmental Protection Agency (19) the ratio of RSP to nicotine when the chamber had people in it was 13 g RSP/g nicotine. In the empty chamber, the ratio was determined to be 3.0 g RSP/g nicotine, a ratio consistent with the value obtained for sidestream smoke (3,5,7,11) and in inert chambers (13,14,50,52). It has been suggested that nicotine may be a good tracer of environmental tobacco smoke particles in indoor environments. However, experiments conducted in indoor environments indicate that the observed ratio of particles to nicotine present in atmospheres dominated by smoking varies from 3 to 80 g RSP/g nicotine (7,15,50,53,57-61), Figure 2. The ratio generally increases with increased residence time and/or decreased total nicotine concentrations. This same trend is observed for the limited data which are available on concentrations of nicotine and concentrations of UV-PM, which is believed to be indicative of the RSP originating from environmental tobacco smoke (28,66). Because of the rapid removal of nicotine from indoor environments, the use of nicotine as a tracer and of nicotine and its metabolites, cotinine and 3-hydroxycotinine, as biological markers for determining exposure to environmental tobacco smoke in studies of passive smoking has been questioned (15,28,29,50). The measurement of gas phase nicotine or even total nicotine may underestimate exposure to the particulate phase and possibly other components of environmental tobacco smoke.

There are a few studies which report changes in the chemical composition of environmental tobacco smoke as it ages in an indoor environment. In the absence of external oxidizing agents or UV light, NO in environmental tobacco smoke is only very slowly converted to NO_2, HNO_2, and possible organic nitrogen-oxide compounds (13). In the presence of a strong UV light source, this conversion is rapid (13). In addition, under these extreme conditions, the photochemistry

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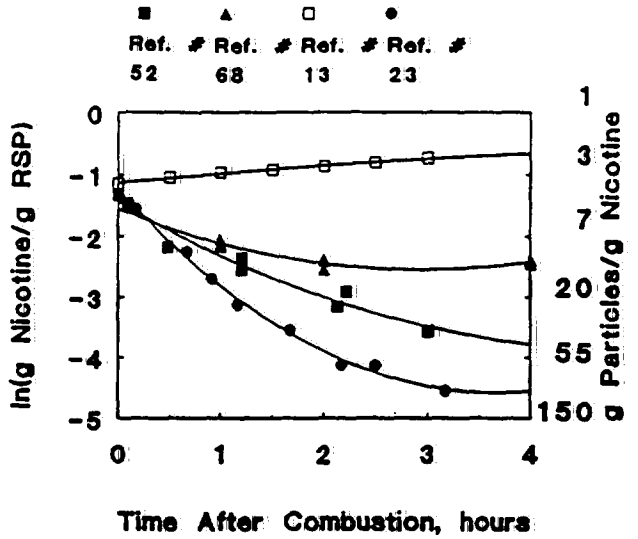

Figure 1 Change in the ratio of nicotine to RSP with time in chamber and controlled indoor experiments (Data are from reference 28).

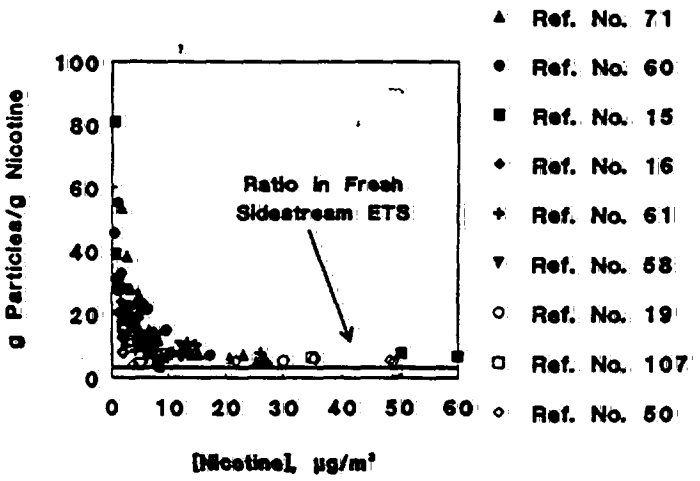

Figure 2 The ratio of RSP to nicotine as a function of nicotine concentration in indoor environments. The concentration of nicotine on the abscissa is divided by 2 for the open data points (from reference 28 and 50).

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leads to the doubling of total particulate matter, the reduction of gas phase basic compounds, loss of solanesol and photochemical alterations in the N-containing bases of environmental tobacco smoke (13,39,40,49). The exact chemical reactions taking place are not known. Under more realistic conditions where some oxidants are introduced into an indoor environment from the ambient air (22), the same reactions appear to occur but at a greatly reduced rate.

These changes in environmental tobacco smoke composition over time complicate the assessment of health effects associated with exposure, and may preclude the accurate measurement of human exposure to specific compounds without actual measurement of the compounds of interest.

TRACERS OF EXPOSURE TO ENVIRONMENTAL TOBACCO SMOKE

The assessment of environmental tobacco smoke exposure is complicated by the presence of significant amounts of organic material in both the gas and the particulate phase and by changes in the relative composition of the two phases with time. The development of accurate markers for estimating exposure to environmental tobacco smoke will be dependent on the determination of the chemical composition of both the gaseous and particulate components of environmental tobacco smoke and the elucidation of changes in that composition with time in indoor environments. As summarized in the National Academy of Sciences review (2), a suitable tracer for quantifying environmental tobacco smoke exposure should be:

- unique or nearly unique to environmental tobacco smoke.
- easily detected in air, even at low smoking rates.
- similar in emission rate for a variety of tobaccos.
- in constant proportion to compounds in ETS which affect human health.

One of the major shortcomings of many studies is that only one measure of exposure to environmental tobacco smoke was determined. Therefore, there is no way to assess whether the concentration of the species studied is (or is not) related to the components in environmental tobacco smoke which may be hazardous to health.

Chemical tracers of environmental tobacco smoke used to assess exposure in the past have included RSP, CO, NO_x and nicotine. Recent reviews of environmental tobacco smoke studies by the National Academy of Sciences (2) and the U.S. Surgeon General (1) reach the same conclusion: the only tracers previously used which may be related to actual exposure to environmental tobacco smoke are concentrations of nicotine and RSP.

CO and NO_x as Tracers of Environmental Tobacco Smoke.

Components of environmental tobacco smoke which are not specific to ETS but which have been used to assess exposure to environmental tobacco smoke include CO (1,25,46,57,63,64) and NO_x (1,46,56). Both of these gases can be measured in indoor environments by a variety of techniques as illustrated in the referenced articles. Comparison of the chemical composition of environmental tobacco smoke in chamber experiments, Table II, (13,14,17,18,64,65) and the relationship between CO concentrations and other constituents of environmental tobacco smoke in indoor environments suggests that the majority of the CO in indoor environments comes from sources other than environmental tobacco smoke. Chamber experiments show the ratio of CO to RSP in environmental tobacco smoke is about .2 to 0.4 mol CO/g RSP, Table I and II, (14,17,64,65). The ratio of CO to RSP in restaurants impacted by modest levels of smoking has been reported to average about 4 (57) and 1.0 (66), and in a variety of homes and offices where smoking occurred at modest levels the ration of CO to RSP varies from 0.4 to 6 and averages 2 (14). Even in environments such as taverns, discos, bus terminals and restaurants, where the major source of particulate matter is from smoking,

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the CO to RSP ratio varies from 0.4 to 1.5 and averages 0.7 mol CO/g RSP (15,64,65) which is generally higher than seen in controlled chamber experiments. Measurements in restaurants of CO and UV-PM (a measure of particulate matter more specific to ETS, see next section) give a ratio of CO to UV-PM of 1.7 mol CO/g RSP (66), a ratio about five times that expected from environmental tobacco smoke. The recent study of environmental tobacco smoke in restaurants (66) included the determination of CO in the outdoor environment. The outdoor CO concentrations averaged about half of the indoor CO concentrations. Correcting the indoor restaurant data for the measured outdoor concentrations gives a minimum ratio of non-ambient CO to UV-PM of 0.9 mol CO/g UV-PM, about three times the expected ratio. Clearly, the majority of the CO in indoor environments comes from sources other than environmental tobacco smoke. Similarly, the ratio of NO_x to RSP reported in indoor environments varies from values comparable to that found in environmental tobacco smoke to ratios which are higher by factors of up to 10 (10). In addition, NO and NO_x have been shown to be only weakly correlated with CO from environmental tobacco smoke, even in a controlled indoor environment (56). The results available to date show that CO and NO_x concentrations will significantly overestimate exposure to environmental tobacco smoke (28).

Nicotine.

The only tobacco specific compound which has been used extensively in the past to determine exposure to environmental tobacco smoke is nicotine (15,19,53,54,57,58,61,67-69). It might expected that determination of the concentration of nicotine in an indoor environment would give a good measure of exposure to environmental tobacco smoke. The use of nicotine as a tracer of environmental tobacco smoke is complicated because nicotine is found primarily in the gas phase (18,20,36-38,53,54,57) and because gaseous nicotine is removed at a faster rate than particulate phase nicotine or the particulate portion of ETS (15,20,22,23,50,57). Thus the concentration of gas phase nicotine underestimates exposure to the particulate phase of environmental tobacco smoke and possible to the concentration of many gas phase environmental tobacco smoke constituents, e.g. see Figure 2 and related discussion in text.

Estimation of exposure to environmental tobacco smoke based on the determination of nicotine has been done both by determining airborne concentrations of nicotine and also by determining the concentration of nicotine and its principal metabolite, cotinine, in body fluids (68,70-88). Studies in which exposure has been determined by the use of questionnaires, and dose measured by urine levels of nicotine and cotinine (72,75,76-79,81,82,84,85,89) have generally yielded poor correlations between exposure and dose. In contrast, studies which have determined urine clearance of nicotine and/or cotinine and have also directly measured nicotine (68,76,77) or ETS (90) exposure have yielded better correlations when the measurements were made over time intervals for exposure which are long compared to the rate of clearance of the compounds from the body (71,74,91-94). However, it is now known that determination of exposure to ETS by measurement of gas phase (or total) nicotine probably underestimates exposure to many components of environmental tobacco smoke in most indoor environments by as much as an order of magnitude. This is due to the rapid removal of gas phase nicotine as compared to many other constituents of environmental tobacco smoke (2,10,15,20,22,23,28,29,50,52,57). The usefulness of nicotine and cotinine as biomarkers of exposure to constituents of environmental tobacco smoke is limited by the viability of nicotine itself as a surrogate for environmental tobacco smoke.

Respirable Particulate Matter.

Total RSP is the tracer for environmental tobacco smoke most extensively used in past studies (1,2) because of the ease with which it may be measured. Even though RSP is elevated in environments where smoking is present, about one half of the RSP in these indoor environments comes from sources other than

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environmental tobacco smoke. RSP thus overestimates exposure to environmental tobacco smoke (15,25,66,96). The measurement will be even more insensitive for the determination of ETS exposure as controls are implemented and the concentration of tobacco smoke decreases in controlled environments.

A technique which has the promise of being specific for particulate matter from environmental tobacco smoke (47,62,66,101) is based on the measurement of the UV absorption of a methanol extract of the collected particulate matter. The resulting measure is referred to as UV-PM, UV determined particulate matter. The UV-PM measurement is better correlated with the estimated amount of environmental tobacco smoke than is the corresponding measurement of nicotine (28,62,66). The measurement of UV-PM may provide a specific measure of particulate matter from only environmental tobacco smoke (62,66,101) but additional work needs to be done to determine if other sources of RSP may contribute to the UV-PM concentrations.

Particulate Mutagens.

Studies of particulate mutagens in indoor atmospheres suggest that environmental tobacco smoke may be the principal source of mutagenic compounds in particles present in indoor atmospheres (55,59,68,98,99). While there are many potential sources of mutagens in the environment (100-103), current data suggest that environmental tobacco smoke is the principal source of particulate mutagens in indoor environments (19,55,99) and that the emission rate of mutagenic material in the particulate phase of environmental tobacco smoke is constant (65,99). The mutagenic activity of particulate matter in rooms where smoking is occurring is much higher than concentrations seen in the absence of smoking, and the mutagenic activity is correlated with the number of cigarettes smoked (55) and is consistent with the results of chamber experiments (19). However, the determination of particulate mutagens in indoor environments requires the use of specialized microsuspension techniques (55,65).

McCurdy, et al. (59) have reported on the simultaneous determination of the mutagenicity of particulate matter, concentrations of RSP and concentrations of nicotine in a bingo parlor and in a casino. A comparison of the observed concentrations of RSP and mutagens (28,59) indicates that in the environments studied there is a background of non-mutagenic particulate matter of about ** g/m^3 with increasing mutagenicity of the particulate matter as the concentration of environmental tobacco smoke RSP increases. The mutagenicity of this ETS-RSP agrees with the mutagenicity of ETS determined in chamber studies (65,99). The data also indicate that nicotine from environmental tobacco smoke is lost more rapidly than either RSP or nicotine in the indoor environment and that the concentration of nicotine leads to an underestimation of environmental tobacco smoke particles and particulate mutagenicity (28). The loss of nicotine may also explain the lack of correlation of RSP mutagenicity with biological measures of exposure, i.e. urine concentrations of cotinine and nicotine in the population studied (59). Further studies on the potential use of mutagenicity as a measure of exposure to environmental tobacco smoke are needed. It should be noted that urine mutagenicity cannot be used to assess exposure (2,87, 105,106) because of the effect of other sources of mutagens, such as diet.

Other Potential Conservative Tracers of Environmental Tobacco Smoke.

The fourth criteria from the National Academy of Sciences review of environmental tobacco smoke (2) listed in the introduction to this section requires that a tracer for assessing exposure to environmental tobacco smoke be present in the indoor atmosphere in constant proportion to compounds in environmental tobacco smoke which affect human health. The tracer which has been emphasized in studies conducted to the present is gas phase nicotine. While gas phase nicotine meets the requirements of being unique to ETS, being easily measurable in the environment and having a similar emission rate for many commercial brands of cigarettes, the concentration of nicotine relative to most other constituents of environmental tobacco smoke is not constant in an indoor

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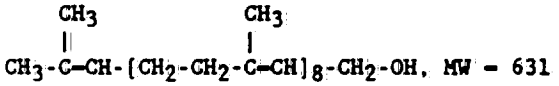
environment. The initial data available on the two tracers, UV-PM (62,66) and particulate mutagens (71), indicate that these may be conserved relative to most components of environmental tobacco smoke in an indoor environment. It is not clear, however, that the measurement of these two tracers will be unique to environmental tobacco smoke, especially at low concentrations of emission and subsequent exposure to a population. In addition, neither of these two tracers can be used to develop techniques for the assessment of biomarkers for determining human dose. Additional tracers are needed.

The results from studies by Brigham Young University (15,22,23) and a larger study by R.J. Reynolds Tobacco Company (66) suggest that 3-ethenylpyridine may be a conservative tracer of environmental tobacco smoke in indoor environments. This compound is present at about concentration expected relative to environmental tobacco smoke particulate matter in a variety of indoor environments (15,22). In contrast, the relative amount of nicotine present in indoor environments is much lower than expected based on the chamber experiments because of the selective loss of gas phase nicotine. The potential use 3-ethenylpyridine as a tracer of RSP in environmental tobacco smoke should be studied further. 3-ethenylpyridine is present only in the gas phase in the indoor environment and may be determined using passive sampling devices (14), diffusion denuders (14,15) or sorbent beds (22,39,40,66). In fresh environmental tobacco smoke there is about 9 times as much nicotine as 3-ethenylpyridine, Table I. However, because of the selective loss of gas phase nicotine in indoor environments, the concentration of gas phase 3-ethenylpyridine in indoor environments is comparable to the concentration of gas phase nicotine (15,22). 3-Ethenylpyridine may be determined with a detection limit comparable to that for nicotine using similar sampling systems.

A compound unique to the particulate phase of environmental tobacco smoke which should be studied as a potential tracer is solanesol (21,49,66,104). Solanesol, (3,7,11,15,19,23,27,31,35-Nonamethyl-2,6,10,14,18,22,26,30,34-Hexatriacontanonaen-1-ol),



$$CH_3-C(CH_3)=CH-[CH_2-CH_2-C(CH_3)=CH]_8-CH_2-OH,\ MW = 631$$

is a trisesquiterpenoid of trans isoprene units which is present at about 3 wt% in the particles from environmental tobacco smoke, Table I. The large molecular weight assures that it will be present only in the particulate phase in environmental tobacco smoke. The compound can be collected by conventional indoor sampling systems and determined by gas chromatography (21,49,56,104), or supercritical fluid chromatography (49). The limited data available to date (21,49,66,104) indicate that the concentration of solanesol in environmental tobacco smoke particles is conserved in the environment.

A recent report by Löfroth et al. (19) of chamber studies of environmental tobacco smoke suggests that isoprene may be used as a gas phase tobacco smoke tracer in indoor environments. The amount of isoprene emitted in sidestream smoke is comparable to the amount of nicotine produced, Table I. In addition, samples collected indoors and outdoors of a tavern indicate that background concentrations of isoprene may be negligibly small compared to the indoor concentration from environmental tobacco smoke. Equally important, the ratio of isoprene to RSP, nicotine or particulate mutagenicity from environmental tobacco smoke in the tavern was comparable to that observed in the chamber studies. Additional work needs to be done in indoor environments with lower concentrations of environmental tobacco smoke to determine if isoprene is a conservative tracer and to establish if other sources, such as vegetation, may be significant.

Gas phase 3-ethenylpyridine and isoprene, and particulate phase solanesol may be good tracers for environmental tobacco smoke (15,21-23,65,66,104).

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However, the viability of these compounds as tracers for assessing exposure to environmental tobacco smoke has not yet been extensively tested (15,66). The relationships among these compounds and between these compounds and other constituents of environmental tobacco smoke in indoor environments needs to be established. If 3-ethenylpyridine and/or isoprene are shown to be conservative tracers for both many gas phase constituents and for the particulate phase of environmental tobacco smoke, then these could possibly serve as the basis for a tobacco specific passive monitor or for a biomarker for assessing exposure to environmental tobacco smoke.

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